

Design of acceleration chamber and dees for the 225-cm cyclotron at the Nobel Institute for Physics, Stockholm

By HUGO ATTERLING

With 11 figures in the text

1. Introduction

The purpose of the present paper is to describe the acceleration chamber (or dee tank) and the dees for the new cyclotron at the Nobel Institute for Physics in Stockholm. This cyclotron has a pole diameter of 225 cm and is of the conventional type (i.e., operating without frequency modulation).¹ The chamber and the dees have been designed for accelerating ions to a maximum radius of 90 cm.

2. Acceleration chamber

General remarks. Small cyclotrons usually have acceleration chambers of brass or bronze with top and bottom lids of iron acting as extensions of the magnet poles.² Rubber gaskets ensure tightness between the lids and the chamber proper. The design of a chamber for a large cyclotron involves the problem of providing a vacuum tank which can withstand very high strains, caused by the atmospheric pressure and by magnetic forces. In order to satisfy all requirements as to vacuum tightness and mechanical rigidity, the chamber for the 225-cm cyclotron at the Institute has been built as an all-welded structure. All those parts of the chamber which must be non-magnetic are made of stainless steel (Avesta 832 P).

Details of design. Fig. 1 is a schematic drawing of the chamber without side cover plates. The two slightly conical iron plates³, which act as pole tips, are welded to frames of non-magnetic stainless steel to form the top and bottom plates. The smallest diameter of the 125 mm thick iron plates is 2 100 mm. Between the top and bottom plates are eight vertical posts of stainless steel, welded to the frames (see "View from A-A" and "View from C-C"). These posts space the pole tips 330 mm apart and are dimensioned and placed with respect to the desirability of obtaining as large side ports as possible. The dees are pushed into

¹ A report on the complete cyclotron will be published later by H. ATTERLING and G. LINDSTRÖM.

² Compare M. STANLEY LIVINGSTON, J. App. Phys. 15, 2, 1944.

³ The conical shape of these plates was suggested by Dr. L. DREYFUS of the ASEA Co., who is responsible for the basic design of the magnet.

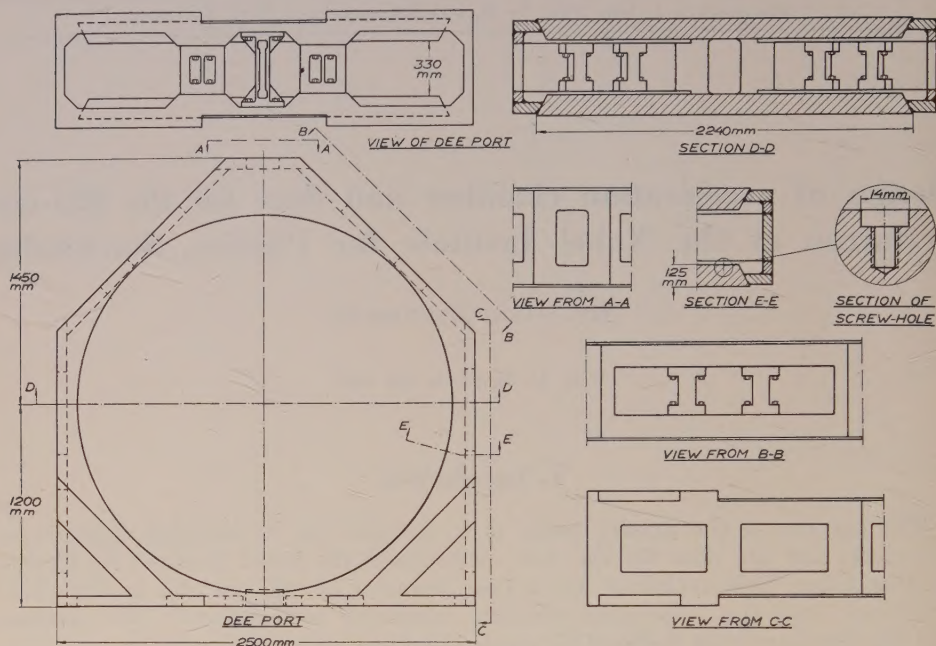


Fig. 1. Schematic drawing of the chamber without side cover plates.

the chamber through the large back opening (the dee port). The opposite part of the chamber is shaped to allow free passage for the deflected beam. In each of the two large side openings (see "View from B-B") two movable stainless steel posts are mounted by means of 7/8 inch brass bolts. These posts can be placed in several different positions within the opening. This arrangement permits the posts on that side on which the beam will emerge from the chamber always to be placed in such a way that they do not intercept the beam. In the dee port are three movable posts as shown in the figure. The centre post has a vertical slit for the ion source. When pushing the dees into the chamber or pulling them out, the two side posts must be removed.

Fig. 2 shows two photographs of the chamber.

All inner surfaces of the chamber are covered with 2 mm thick copper sheets serving as r-f liners. Water-cooling is provided for all liners, which for this purpose have a network of cooling pipes silver-soldered to the back side. The liners are divided into several sections and the pole tips can be uncovered (e.g., for inserting shims¹) without removing the copper liners on other parts of the chamber. The edges of the liners in the chamber openings are provided with fingers of beryllium-copper making contact with the cover plates when these have been attached to the sides of the chamber.

Magnetic shims to shape the field and the central copper liners are screwed to the inner surfaces of the pole tips, which for this purpose are provided with

¹ Compare R. R. WILSON, *J. App. Phys.* 11, 793, 1940.

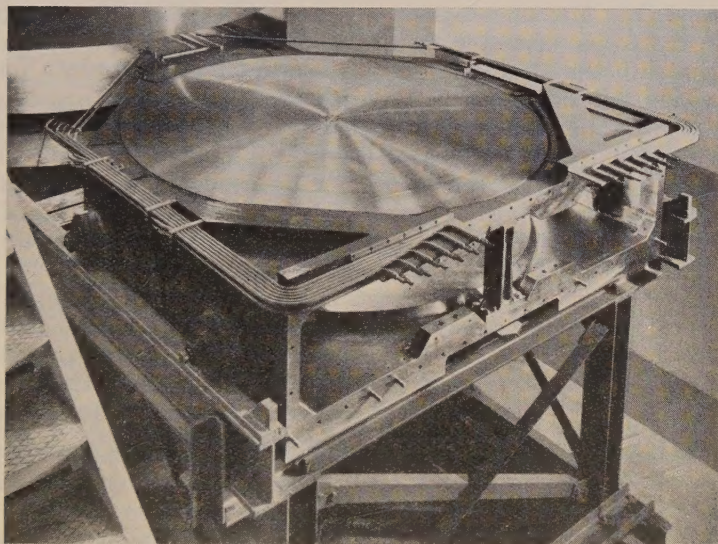
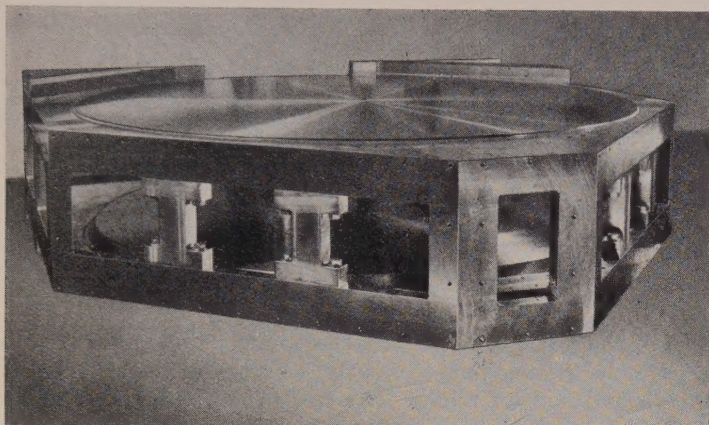


Fig. 2. Photographs of the chamber; cf. Fig. 1. The lower picture shows the chamber before it was mounted in the magnet gap.

a large number of screw holes. One of these holes is shown in Fig. 1. Unused holes are plugged with special screws of soft iron. Each of these screws has a channel in the centre for evacuation of the air pocket at the bottom.

The dee port is closed by means of a cover plate of non-magnetic stainless steel having two short tubes for connection to the dee line tanks (see Fig. 11). This cover plate has a centre slit through which the ion source can be inserted. On each side of this slit is an opening for inserting and removing the side posts. These small openings and the other ports of the chamber are closed with aluminium plates.

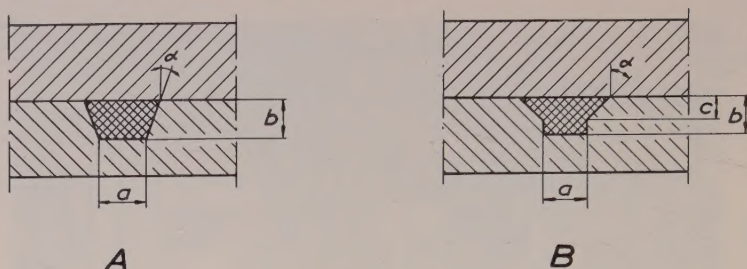


Fig. 3. Rubber gasket vacuum seals.

The surfaces of the iron plates were machined after these plates had been welded to the stainless steel frames but, obviously, before the vertical posts were welded between the top and bottom plates. The welding of these posts had therefore to be carried out very cautiously in order to avoid warping of the chamber plates. This work was performed with great skill by the manufacturers, Avesta Jernverk (Avesta Steelworks). Measurements of the distance between the pole tips at eight points near the edges showed a maximum discrepancy of only about 0.1 mm, representing a sufficient degree of accuracy. Several measurements for the purpose of checking this difference proved that it remained unchanged for a period of about 6 months after delivery of the chamber. This shows that the structure is stable. The movable posts in three of the side openings allow small adjustments of the distance between the iron plates, for by changing the length of the posts slightly, the plates may be pressed apart or drawn towards one another. The adjustments which can be made in this way are of the order of 0.1 mm.

The chamber is fixed between the poles of the magnet by 8 clamps which are screwed to the bottom plate and engage in a groove round the top of the lower pole. When the clamps are removed, the chamber, which weighs about 10 tons, can be rotated about the pole axis. This is achieved by moving it on three bogies rolling on a brass-track supported by the lower pole. This greatly facilitates the placing of the chamber in the correct position in the magnet.¹

Vacuum seals. The gaskets used for the seals between the cover plates and the chamber are made of 5 by 5 mm rubber strips, of which the ends have been vulcanized together. The gasket grooves are machined in the cover plates. Two types of grooves are used, as shown in Fig. 3. A common feature of these grooves is that the cross section area is equal to the cross section area of the gasket. When compressed 1 mm, the gasket will practically fill up the groove. The dimensions of the groove shown in Fig. 3 A are $a = 5$ mm, $b = 4$ mm, $\alpha = 20^\circ$. This groove is preferable in so far as it causes only slight deformation of the gasket. It has, however, the disadvantage of being unable to keep the latter in position during assembly. When mounting a cover plate with such a groove, clips must be used to hold the gasket in place until it has been pressed against the opposite seat. Experiments have shown that the following dimensions of the groove illustrated in Fig. 3 B are suitable: $a = 4.7$ mm, $b = 4$ mm, $c = 2.5$ mm, $\alpha = 45^\circ$. The gasket is firmly attached in this groove and no clips are required.

¹ The arrangements for fixing and rotating the chamber were designed in collaboration with Mr. E. LADELL of the ASEA Co., who is responsible for that part of the design which concerns the magnet pole.

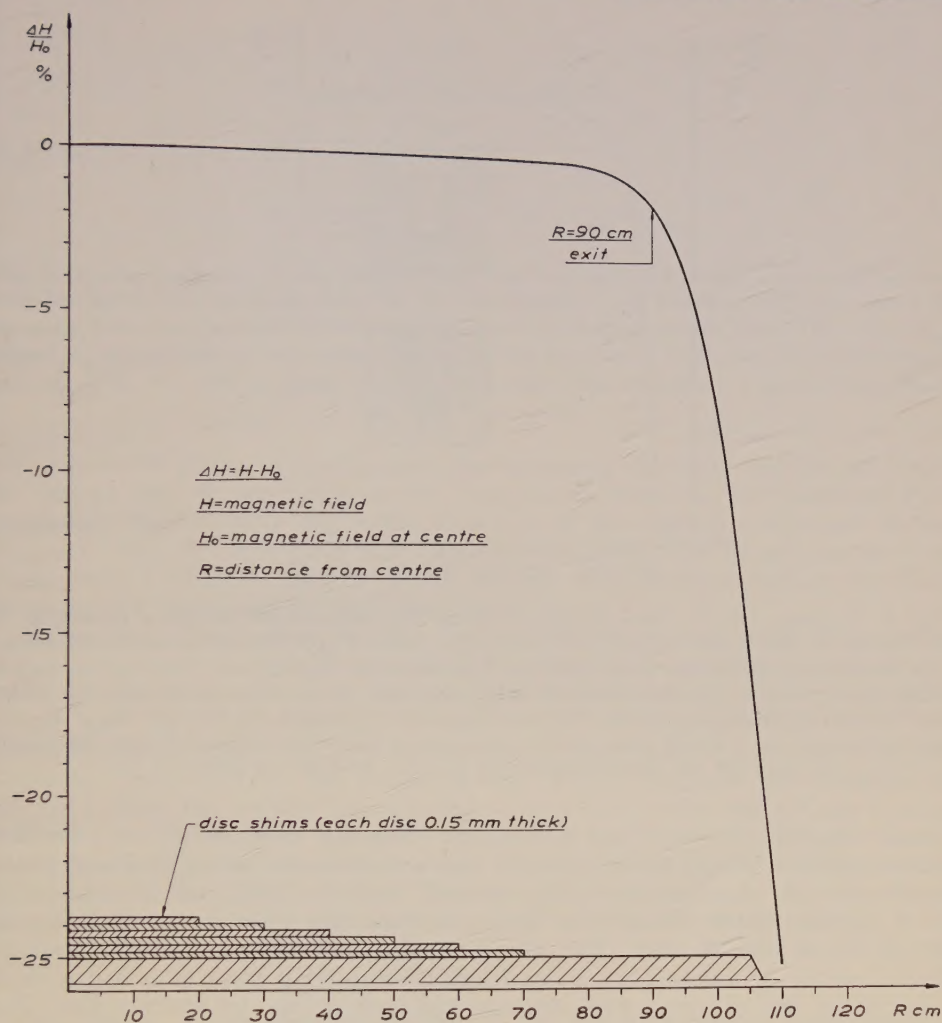


Fig. 4. Radial variation of the magnetic field when the chamber is evacuated. The field at centre (H_0) is 11 600 oersteds.

In large cover plates two parallel grooves are used, but it has not been found necessary to make provisions for pumping out the region between the gaskets. The use of two parallel gaskets ensures sealing in case of failure of one of them. A film of vacuum grease is usually applied to the gasket surfaces.

A 1 mm compression of the gasket gives adequate sealing. Tests have been made with a helium leak detector and no leaks found due to gaskets of the types described.

Shimming. As already mentioned, the correction of the magnetic field to provide magnetic focusing of the ion beam can be achieved by means of shims

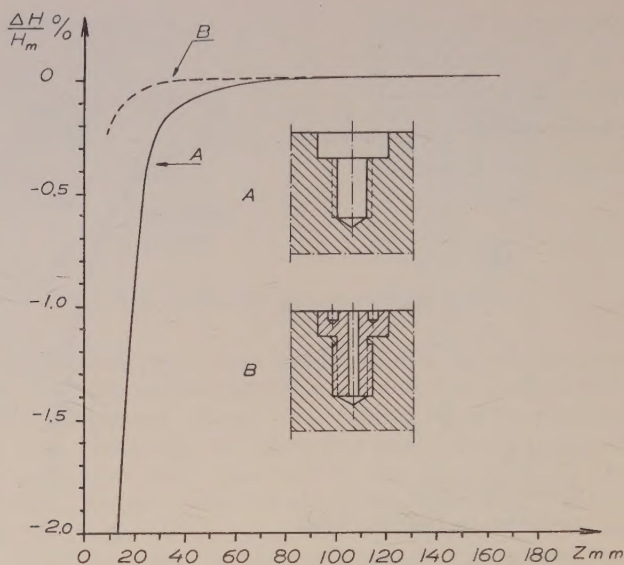


Fig. 5. Variation of the vertical field H along the vertical axis through a screw-hole, A without screw and B with screw. $\Delta H = H - H_m$, where H_m is the field at the median plane; z is the distance above the lower pole tip. The lower dee edge is at $z = 90$ mm, the median plane is at $z = 165$ mm. The measurements were made above a screw-hole near the centre of the chamber before the shims shown in Fig. 4 were installed. In this case $H_m = H_0$, the field at centre. $H_0 = 10\,900$ oersteds. The diameter of the screw-head is 14 mm. The search coil used for the measurements had an outer diameter of about 23 mm.

placed against the pole tips inside the chamber. The shims now installed consist of two flat-pyramidal piles of thin iron discs symmetrically placed in the centre of the chamber, one pile on each pole tip. Each pile is constructed of 6 circular sheets of soft iron 0.15 mm thick, the respective radii being 20, 30, 40, 50, 60 and 70 mm. The pile is divided into two semi-circular sections. Each section is screwed to a semi-circular supporting plate of a 3 mm thick brass sheet and provided with stepwise arranged cavities for the iron discs. The supporting plates with the shims are fastened between the copper liners and the pole tips.

The shims described here were installed after some measurements of the magnetic field with preliminary shims. A search coil¹ and a fluxmeter were used for measuring the field. The coil was moved in steps of 25 mm along a diameter in the chamber, thus measuring gradients. The arrangement was such that the chamber could be evacuated during the measurements. To make this possible, the coil was enclosed in a vacuum-tight box of plexiglass, which was vacuum-tightly connected to a brass tube serving as a covering for the leads from the coil, this brass tube being movable through a vacuum seal in one of

¹ This coil as well as the coils mentioned further on were calibrated in a field of known strength. The calibration was performed by means of an apparatus for measurement of nuclear magnetic moments (K. SIEGBAHN and G. LINDSTRÖM, *Ark. f. Fysik*, *1*, 193, 1949). Dr. Lindström kindly assisted in making the calibrations.

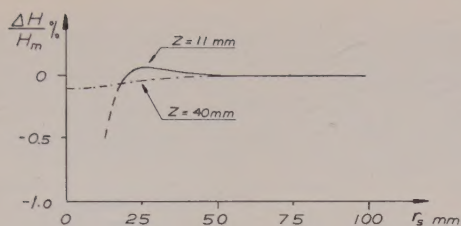


Fig. 6. Radial variation of the vertical field H in two different planes above a screw-hole with the screw removed (case A in Fig. 5). The distance r_s is measured from the centre of the screw-hole along the radius of the iron plate; z is the distance above the plate. $\Delta H = H - H_m$, where H_m is the field at the median plane ($z = 165$ mm) for $r_s = 100$ mm, and in the actual case $H_m = H_0$, the field at centre. $H_0 = 10\,900$ oersteds. The curve for $z = 11$ mm drops down to -2.4% at $r_s = 0$.

the side cover plates of the chamber. For measuring the total field the coil could be rotated 180° at any point on the radius along which the field gradients were measured. Fig. 4 gives the radial variation of the vertical component of the magnetic field obtained with the shims now installed. The measurements were made with a central field of $11\,600$ oersteds. This is approximately the field necessary for producing 25 MeV deuterons.

Before the shims shown in Fig. 4 were installed, several series of measurements were made in order to investigate how the field is influenced by the screw-holes on the inner surfaces of the pole tips. A corresponding series of measurements was made for studying the variation of the magnetic field due to the edges of two 0.5 mm thick disc shims, one on each pole tip. Search coils and fluxmeter were used for this survey as well. Fig. 5 illustrates the variation of the field along the vertical axis through a screw-hole with and without a screw respectively. Fig. 6 shows the radial variation of the field in two different planes above the hole if the screw is removed. Fig. 7 gives the radial variation of the field intensity in different planes between the two disc shims. In every case, measurements were made only of the vertical component of the field.

3. The dees

The design of the dees was based on the following general considerations, amongst others.

- 1) For electrical and constructional reasons it was desirable for the two dees to have the same shape and dimensions.
- 2) All parts of the dees should be thoroughly water-cooled.
- 3) It appeared desirable to connect the dee and the dee stem by means of a supporting frame placed inside the water-cooled dee skin.
- 4) This supporting frame should itself be rigid and afford firm fixation of the dee. In addition, it should be dimensioned in such a way as to allow an internal deflector to be placed in one of the dees.
- 5) The dees should be provided with demountable feelers.

As a result of these considerations the design was that shown in Figs. 8–11. Each dee consists of three parts: the semi-circular part, the supporting frame and the frame house. The first-mentioned is made of 2 mm thick copper sheeting

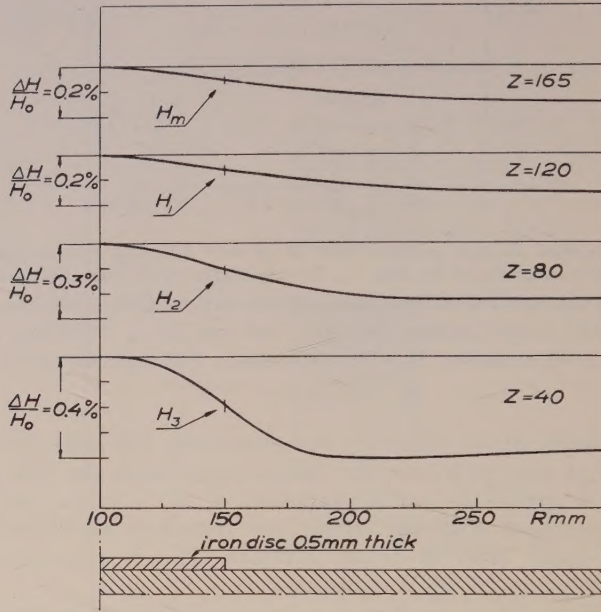


Fig. 7. Radial variation ΔH of the vertical field in different planes between two disc shims (the lower disc is indicated). The vertical distance z is measured from the lower pole tip (the median plane is at $z = 165$ mm). R is the distance from the centre of the chamber. H_0 is the field at centre; H_m , H_1 , H_2 and H_3 are the different values of the field at $R = 150$ mm (corresponding to the edge of the shims). In the actual case the following values were measured: $H_0 = 10\,900$ oersteds; $H_1 = 1.0001 \times H_m$; $H_2 = 1.0003 \times H_m$; $H_3 = 1.0008 \times H_m$.

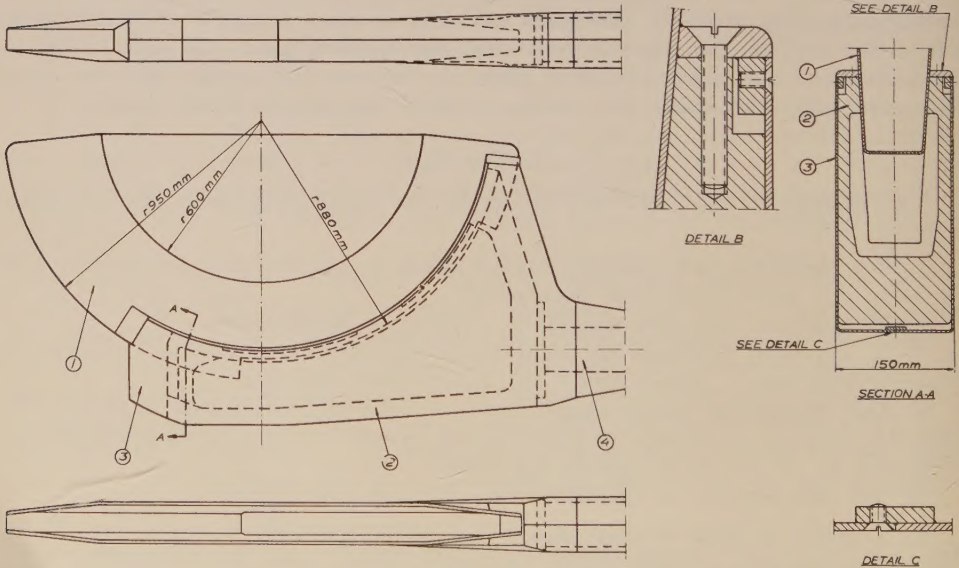


Fig. 8. Schematic drawing of the dee. The figures denote: 1 semi-circular part; 2 supporting frame; 3 frame house; 4 supporting steel tube.

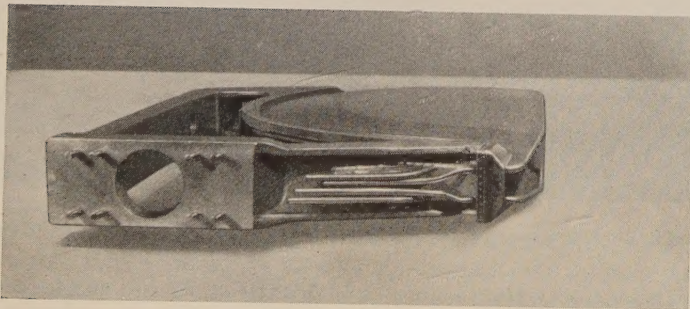
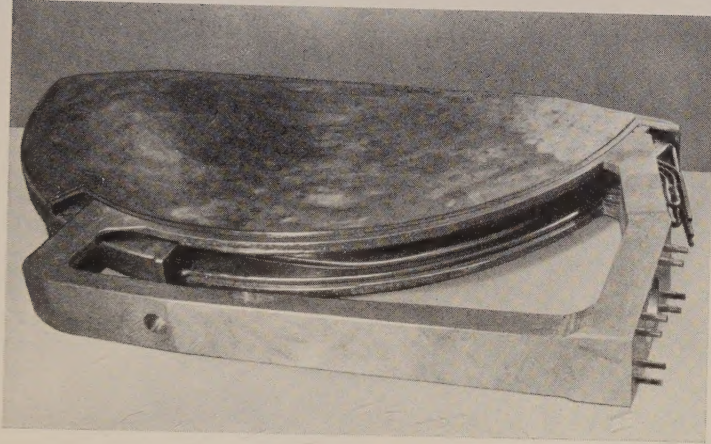
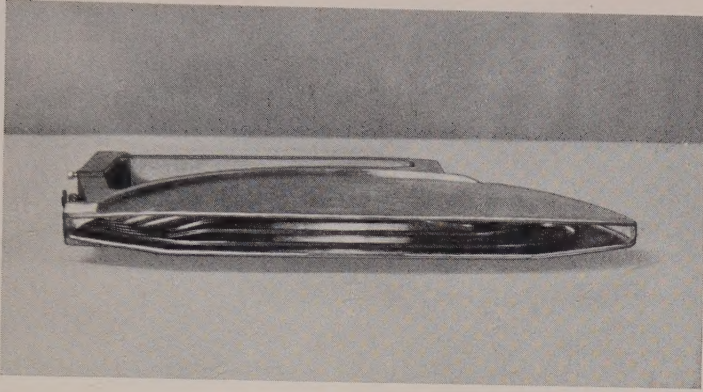


Fig. 9. One dee with frame house removed; cf. Fig. 8.

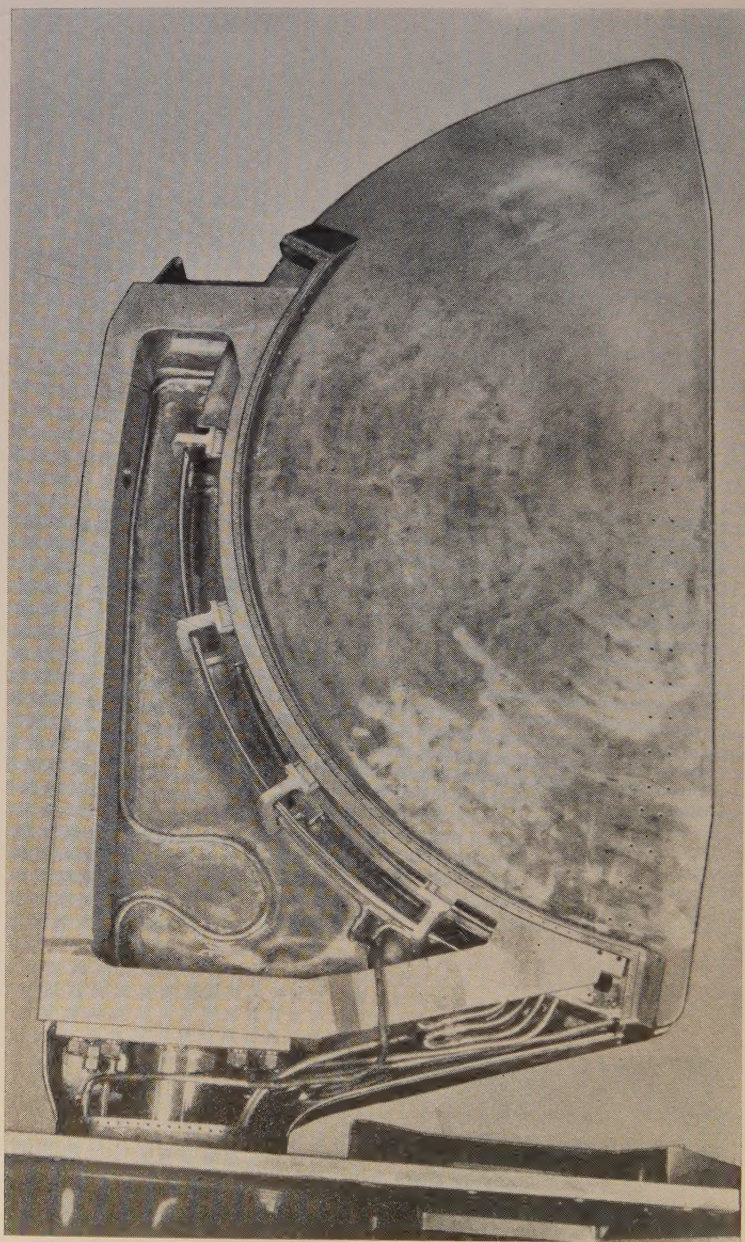


Fig. 10. One dee with the upper half of the frame house removed.

with copper pipes for water-cooling, silver-soldered to the inside surfaces. The supporting frame is made of an aluminium alloy and is of ample dimensions and very rigid. By means of eight $\frac{5}{8}$ -inch brass bolts this frame is fastened to a

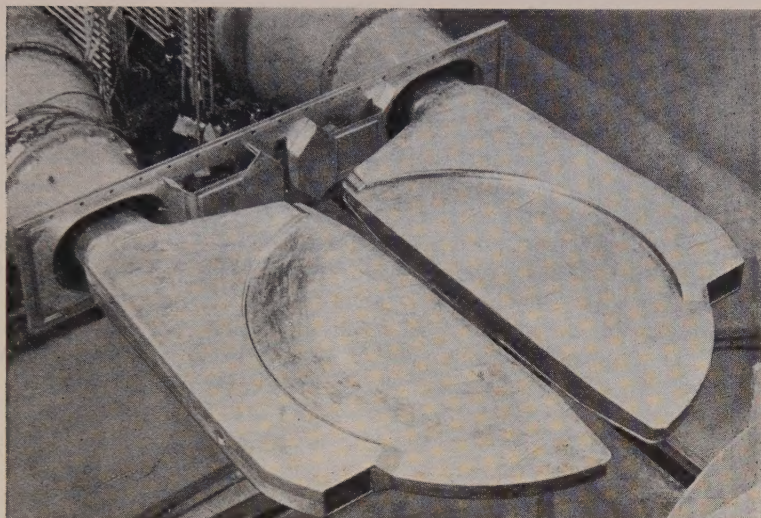


Fig. 11. The dees and the dee port cover plate.

steel tube, which at the same time acts as a support for the inner conductor of the dee line. The front part of this supporting tube is made of non-magnetic stainless steel. The frame house, consisting of two halves, is made of 2 mm thick copper sheeting with internal cooling pipes and is screwed to the semi-circular part by monel screws. Inside the frame house the side wall of the semi-circular part of the dee is cut away. The opening thus formed is closed by a water-cooled copper plate bent in a circular shape and easily removable. This plate can be seen in Fig. 10. In one of the dees the copper plate is only temporarily mounted until the construction of the deflector is finished. It is then replaced by the deflector exit strip. In the other dee the opening formed by removing the copper plate mentioned can be used for inserting targets in the dee through the hollow dee stem.

Feelers can be fastened to the dee faces with screws. The feelers must be provided with water-cooling. The cooling lines for each feeler are silver-soldered to a copper bar, screwed to the inner surface of the dee skin together with the feeler. The cooling lines are connected to water-conducting pipes in the dee stem, the connexions being placed internally in the frame house. With this arrangement, the feelers can easily be changed or removed for repair. In Figs. 8—11 the dees are shown without feelers.

The connexion between the dee neck and the inner conductor of the concentric dee line is made by monel screws.

The shape of the semi-circular part of the dee has been determined with respect to the focusing of the beam and in view of the necessity of keeping the dee capacity low. By enlarging the dee in the side direction to accommodate a heavy supporting frame it has been possible to make the dee somewhat low without endangering the stability. In fact, the dees have so far proved to be stable and rigid.

4. Concluding remarks and acknowledgements

The designs described in this paper were started in the spring of 1946 with a preliminary calculation of the internal deflector and a study of the deflected beam as well as a study, according to the theories of Rose and Wilson^{1, 2}, of the focusing of the beam inside the dees. For, in order to determine the shape and dimensions of the dees and the chamber it was necessary to take into consideration the deflector arrangement, the path of the deflected beam and the beam profile. Some of these design studies, which had in view the production of 25 MeV deuterons, formed one of the bases for the construction of the scale models of the dees and the chamber which were to be incorporated in a model setup for studying the r-f system.³ After the model experiments had been made, the shape of the dees and the chamber were slightly modified for constructional reasons. The design of the chamber was finished at the end of 1946, and the chamber was delivered by Avesta Jernverk in May, 1948. The design of the dees proceeded in stages and the construction was essentially completed in the summer of 1948.

Finally, I wish to express my gratitude to Professor MANNE SIEGBAHN for his kind interest in this work. I should also like to thank Docent S. KASARNOWSKY, Chief Engineer of Stockholms Hamnstyrelse (the Harbour Board of the City of Stockholm), who was consulted concerning the mechanical design and contributed several suggestions. In particular, after the design of the chamber had been worked out in all essential respects, Docent KASARNOWSKY made a numerical check of the deformations and stresses which could be expected in the structure of the chamber under operating conditions and specified the dimensions of the welds and bolt joints. I am also indebted to my colleagues, Tekn. lic. G. LINDSTRÖM, with whom I discussed the design from the electrical point of view, and Civiling. B. ÅSTRÖM, with whom I had some discussions when the design of the chamber was at an early stage. In addition my thanks are due to several members of the technical staff for their assistance, and in particular Messrs. B. AXELSSON, B. FOGELBERG and R. SKOLIN should be mentioned.

Nobel Institute for Physics, Stockholm 50.

¹ M. E. ROSE, *Phys. Rev.*, *53*, 392, 1938.

² R. R. WILSON, *J. App. Phys.*, *11*, 781, 1940.

³ G. LINDSTRÖM, *Ark. f. Mat., Astr. o. Fysik*, *35 A*, N:o 15, 1948. The oval dee neck and the two short tubes which are welded to the cover plate for the dee port (see Fig. 11) were shaped according to suggestions of Dr. Lindström.

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